Low Order Explosive Response

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LONG-TERM GOALS

The Low Order Explosive Response (LOER) program is devoted to increasing the level of understanding for non-detonative explosive reactions that are associated with main charge disruption (MCD) during explosive ordnance disposal (EOD) operations. A second goal is to develop the ability to predict the outcome of a MCD procedure and to develop better tools for main charge attack. To achieve these goals, a basic understanding of the phenomenology of non-detonative reactions is being explored. During FY2001 information from testing will used to develop new material models for TNT and Composition B in ALE 3D and SPH, which can be used to compare future MCD concepts.

OBJECTIVES

The explosive combustion processes controlling the violence of a low order event can occur over tens of microseconds to many milliseconds and are influenced by many parameters. These include but are not limited to penetrator size and velocity, explosive fill and size, confinement strength, and ambient conditions. These system level parameters are typically available to an EOD technician or engineer in the field. Thus, one objective is to quantify the effect these parameters on the combustion process and ultimate reaction violence. This knowledge will help the EOD technician choose the correct tool configuration and procedure to maximize the chances of low order reactions to occur.

Unfortunately, the interplay of those parameters is not straightforward, and a more fundamental understanding of the process is required to reliably predict event outcomes, tool designs, and procedures. Processes requiring a more fundamental understanding include mechanical initiation of burning, damage of the explosive by mechanical load, burning of the explosive under pressure, material behavior and ignition response of explosives and the growth from burning to detonation in non-granular explosives. Thus, a second objective of this effort is to conduct fundamental experiments for these processes and develop models where required.

APPROACH

The scope of this problem has generated the following approach, which is to (1) conduct collaborative efforts between laboratories to understand and model the fundamental processes of low order reactions and (2) conduct carefully conceived field tests to study system level parameters and procedures. By using a series of small-scale experiments, NSWC-IH is conducting model development efforts for explosive mechanical response and initiation. ARL is conducting fundamental low-order reaction experiments, measuring damage parameters, and modeling the effects of the combustion process. Both laboratories are exercising new models in hydrocodes. NSWC is putting an initiation model into EPIC in a related project, and ARL is applying a new damage and reaction model in Sandia National Laboratory's CTH software. NAVEODTECHDIV conducted tests at Fallon Naval Air Station, NV on live, fuzed, and dud Mk-series bombs using the MCD device. RPI is in process of utilizing ALE 3D and SPH to model low order problem associated with impact processes, Drop Weight test, and Hopkins Bar test. The Drop Weight test uses accelerometers, which produce data that can be compared with accelerations, calculated by ALE 3D and SPH. If the Drop Weight test is simulated using ALE 3D and SPH, the results could be compared directly to experimental results produced during testing. This will allow us to validate the new material models going into ALE 3D and SPH.

WORK COMPLETED

ARL Efforts

Specific ARL efforts for FY00 were: (1) continue fundamental low-order reaction experiments on TNT and composition-B to examine the effect of confinement and explosive type, (2) conduct interrupted closed-bomb combustion experiments and SEM analyses on TNT and composition-B to examine the combustion process, (3) model the combustion process inside a confined charge following initiation by a penetrator to illustrate the effects of a vent and compute pressure loading on the main charge and (4) manufacture and ship samples to Lawrence Livermore National Laboratory for testing.

ARL completed a series of tube experiments on composition-B in which the composition-B was pressurized with a piston at two different confinement levels. The piston was pressurized using a small arms powder to pressurization rates similar to what was seen in previous tube experiments where pressurization was due to self-combustion of the explosive. The objective was to identify whether the previously observed secondary-ignition phenomenon would occur with pressurization alone in the absence of convective burning in the explosive.[1,5]

Additional experiments are prepared with instrumented composition-B loaded M107 155-mm artillery shells. These shells were cast with embedded pressure gages. Holes were drilled in the sides of the shell bodies prior to casting and cavities were formed inside the shell to simulate penetration channels created by an MCD device. In current testing, small arms powder is ignited in the shell to pressurize the cavity. A plug is ejected when the pressure rises and the pressure rise due to the composition-B is observed. These tests are also being modeled with the non-detonative combustion model.

Interrupted closed-bomb experiments were conducted on TNT and composition-B grains to study the combustion process. Both TNT and Comp-B are difficult to ignite due to their poor combustion characteristics at low pressure. The partially burned grains were examined with a SEM and burning characteristics were observed.[6] In addition to interrupted closed-bomb experiments, several full-combustion closed-bomb tests were conducted. These experiments provided additional insight into the burning process through a term called vivacity.

Observations of non-uniform ignition of subsurface decomposition and the strong likelihood of particle ejection from the surfaces indicate the inability to define a burning rate in the classical sense for these materials. It may be necessary to define a new relationship in the combustion of these materials that connects pressure, mass generation, and other qualities yet to be determined (time of rapid combustion, initial surface to volume ratio of the charge, RDX particle size, ignition brisance, etc.)

A computer program was written to model combustion of an incompressible energetic material containing an internal cavity of known shape, where the cavity may have a vent or exhaust port. The combustion-driven transient flow field within the cavity (especially the pressure field) along with the changing volume and surface area (i.e., the time-dependent boundary location) are predicted. The user can alter the properties of the energetic material, initial cavity shape, exhaust port area, initial pressure and temperature within the cavity. The model assumes an inviscid quasi-one-dimensional flow field and will account for choked or unchoked exit flow from the vent depending upon the pressure conditions. Optional cavity shapes include rectangular/hemispherical, elliptical, and hyperbolic. Furthermore, the regressing cavity boundary routines sense the presence of an inert lateral boundary when it is uncovered. Pressure-dependent thermodynamic parameters for TNT and COMPB are available within the code.[7]

As a separate exercise, an approximate solution for a rectangular/hemispherical cavity flow field was also derived under the restrictive assumptions of uniform pressure, negligible gas velocity, ideal gas (zero co-volume), isentropic exhaust flow from a choked nozzle, and fixed gas properties. This solution was used to generate a number of solutions that were compared to the full numerical solution to the same problem. The comparisons were excellent, and suggest that the combustion model has been coded correctly.

The full numerical model has been used to predict the behavior of a number of experimental configurations that will contain COMPB. Results are being compared with data from experiments described above. As might be anticipated, the combustion model indicates an extreme sensitivity to the prescribed burning rate of the energetic material. For the two explosives of interest, TNT and COMPB, very little data is available for this fundamental combustion rate as a function of pressure. This has been the incentive to conduct closed-chamber combustion tests at ARL for both materials.

Analyses of ARL closed-bomb tests were conducted. Without going into great detail, considerable insight was gained into TNT and Comp-B combustion from a quantity called "vivacity". Vivacity, essentially (DP/Dt)/P, is a measure of the burning surface which is supporting the combustion process at that instant in time (*assuming* that the pressure burning-rate index is a constant). When vivacity is plotted against the pressure (or P/P_{max}), a positive slope indicates that the burning surface area is progressive (increases with depth burned) and negative slope indicates regressive burning (decreases with depth burned). The latter would be expected from the cylinders used in the ARL experiments if burning were well controlled. The TNT burn rate of Kondrikov {Kondrikov, et. al., Fizika Goreniya I Vzryva, 9(1), 1973} was used to analyze ARL TNT combustion data generated by DelGuercio. Results indicate a fairly good burning process until pressure reaches about 0.2 of its maximum value, at which time the experimental vivacity curve heads sharply positive. Unless the pressure index of the combustion process is increasing (not shown by the Russian data), this strongly suggests that the TNT cylinders are burning “down inside” in some unknown fashion or breaking apart. This is in agreement with the results of the SEM studies previously discussed for the interrupted closed bomb experiments.

For Comp-B, the experimentally determined vivacity shows a significant increase beginning at pressures of approximately 0.2 of Pmax. Analyses of these data using the BRLCB code suggest a burning rate index much greater than unity – possibly near two. By using measurements of recovered grains from interrupted closed-bomb tests, Birk devised an analysis scheme that integrates the pressure-dependent regression rate along the experimental pressure time-history from each blow-out run. The value of total depth burned is then equated to measured value, and the values for the coefficient and pressure index in the burning rate expression are determined. For COMPB, the burning rate pressure index is approximately 1.7 (similar to BRLCB predicted value from full pressure ARL closed chamber runs), and the coefficient is a small number. The consequence of this combination of burning rate parameters is that combustion of COMPB in a closed volume could linger for some time interval at low pressure – and then run away quite abruptly. This conclusion is in qualitative agreement with results of low-order field experiments previously conducted in the MCD program.

This program also leverages ARL mission efforts. In support of this program ARL conducted hot-fragment-conductive-ignition (HFCI) experiments on TNT and composition-B. Measurements were made for the required fragment temperature to ignite TNT and Comp-B. The qualitative results agree with the general burning behavior of these materials observed in other experiments. Plans are to measure the ignition time of these materials as a function of fragment temperature to provide insight into HFCI as an ignition mechanism in low-order impact experiments. ARL is also conducting high-rate shear experiments on several energetic materials using a modified Hopkinson bar. In partial support of this effort, Comp-B was chosen as one of the primary sample materials.

NSWC Efforts

Small-Scale Experiments. In these, a small sample of either the explosive or an inert stimulant (mock) of the explosive is subjected to a prescribed mechanical load and the resulting response (deformation and/or reaction) measured. Two standard small-scale tests will be used - the Drop-Weight (DW) test and the Split Hopkinson Pressure Bar (SHPB). Traditionally, DW is used to measure the sensitivity of explosives to impact, whereas SHPB is used to measure the material behavior. In this work, DW will be instrumented to measure the mechanical response simultaneously. No significant ignition is expected in SHPB.[2,3,4]

High Pressure Tests. Because the behavior of TNT and Comp B is expected to significantly depend on the pressure, high-pressure tests are developed. Small explosive samples will be isotropically compacted and uniaxially compressed at high pressure reaching 150,000 psi. Development of the high-pressure facility at Indian Head is underway using multiple funding sources.

RESULTS

ARL Tube Testing

Composition-B in thick-walled pipes ignited and transitioned to a minimum of a violent reaction at all pressurization rates tested. In some cases these violent reactions transitioned to detonations. For some low pressurization rates, the delay was quite long (as much as 10 ms) once the propellant pushing the piston burned. The pressure history indicates a static compression phase with little or no reaction followed by a rapid reaction, which sends a large compression wave down the column. For higher pressurization rates, the behavior appears essentially the same, but with no static phase. The gage records indicate that a shock is forming in the tube at these high rates. The pressure histories do not indicate a detonation, but a detonation may follow the large compression wave after the gages are destroyed. Witness plates and recovered fragments indicate at least a partial detonation in many instances. Initial examination of strain gage records indicates possible reactions (perhaps detonations) faster than the explosive sound speed, but this may be due to a phase velocity effect.

Composition B in thin walled pipes showed varied reactions as a function of loading rate. It was observed at high pressurization rates, that reaction transitioned to detonation. At low pressurization rates, the reactions were mild. A threshold combination of pressurization rate and pressure level exists in order to get transition to a violent reaction or detonation as a function of confinement. If pressurization rate is high but confinement is low, then the reaction will not grow to detonation since confinement will be lost. But at still higher rates, the reaction can transition since confinement loss cannot overcome the reaction growth.

ARL Closed Bomb Testing

Extinguished grains were analyzed and their morphology indicated that the TNT burned in a very irregular fashion, where as the Comp-B burns more regularly. However, in complete combustion closed-bomb experiments, as pressure increased both materials exhibited high vivacity indicative of a very progressive burning that cannot be attributed to the geometry alone.

During interrupted closed bomb testing extinguished TNT grains showed that TNT exhibits in-depth decomposition (combustion) that spreads as the grain is consumed with the amount of in-depth burning increasing with pressure. This indicates that the assignment of a well-defined combustion surface is not possible.

Extinguished grains of Comp-B show no RDX on any combustion surface. This indicates that the RDX crystals decompose very quickly. This observation combined with the difficulty that TNT exhibits in the ignition process suggests that the Comp-B burning process consists of rapidly decomposing RDX particles creating craters during decomposition and spewing the decomposition products, along with particulate TNT into the flame. These newly formed crater surfaces then undergo re-ignition of the exposed TNT until another RDX particle heats enough to begin its rapid decomposition. The size of the craters left behind match the RDX particle size fairly well. Note that the in-depth burning observed in pure TNT is disrupted here because any differential burning that occurs is destroyed during the rapid RDX decomposition because of the particulate spewing. While this observation is more in line with conventional propellant burning, since it excludes the in-depth process, it still prevents a good assessment of burning rate because no definite surface area can be associated with the mass generation.

During standard closed bomb testing samples were burned through completion and the vivacity curves were plotted. The curves show a highly progressive trace for a grain designed to be a regressive burner. The "new" surface area that causes a progressive burn comes from in-depth burning.

NSWC/IHD Drop Weight and Hopkins Bar Tests Results

Figure 1 shows typical raw data (incident, reflected, and transmitted waves) acquired during testing of TNT. The samples were usually 9.5 mm in diameter and 4-9 mm thick. The stress versus strain illustrated in Figure 2 is the corresponding reduced data. A typical framing camera record of the sample deformation/fracture during loading is shown in Figure 3.

Drop Weight Test. An accelerometer was added to the drop weight in order to measure the sample deformation (integration of acceleration gives the velocity as well as displacement of the weight, from which the sample thickness can be calculated). Four photo-detectors were added in order to detect the onset of ignition. Several TNT and Comp B samples were tested.

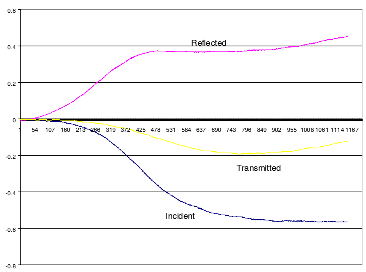

Figure 1. Raw Data for TNT at 275/s

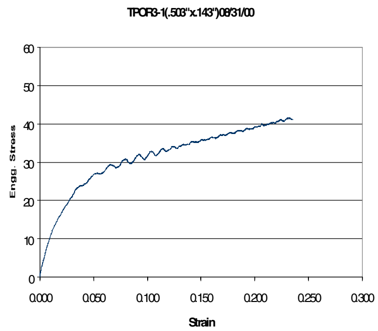

Figure 2. Stress-Strain Curve for TNT at 275/s

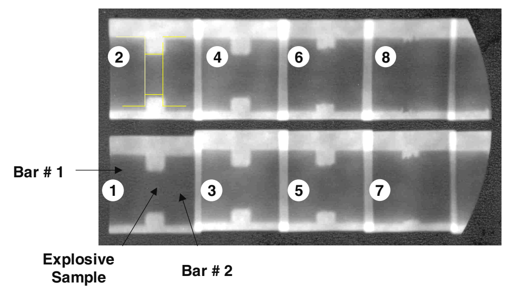

Figure 3. TNT Sample Deformation in Hopkinson Bar (25 μs between frames)

IMPACT/APPLICATIONS

The phenomenology of non-detonative reactions for explosives has been an area of interest as far back as the 1880s and the invention of explosives. The goal of this program is to research past work done in this area, conduct new experiments that will help solve still unknown areas of the problem, and develop a predictive model that will help the EOD community solve current and future problems that exist in the world today. This work has had some impact already on the MCD program, which has evaluated tool concepts and is devoted to deployment of a new tool and procedures for field operations. Future impact will come in the area of improved low order techniques on ordnance with higher energy explosive fills, heavier confinement, insensitive explosive fills, and understanding the effects of mechanical damage (cracking, crushing and shrinkage).

TRANSITIONS

Work from this program has already been transitioned to the existing MCD effort. Tool developers are using the experimental knowledge gained to improve the current generation tool design and procedures for use. At the conclusion of the effort, an understanding of non-detonative process will permit an improved MCD tool and supporting procedures to be developed in an EOD acquisition effort.

RELATED PROJECTS

ARL hot fragment test project funded with ARL internal funds.

Mortar IM test project funded by Picatinny Arsenal for Composition B fills.

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